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BULLETIN No. 829

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER October 29, 1919

THE MOSAIC DISEASE OF SUGAR CANE AND OTHER GRASSES

By

E. W. BRANDES

Pathologist, Office of Sugar-Plant Investigations

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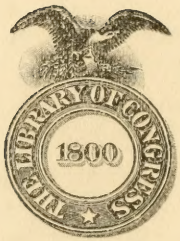

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By E. W. Brandes,

Pathologist, Sugar-Plant Investigations; formerly Pathologist, Porto Rico Agricultural Experiment Station, Mayaguez, P. R.

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HISTORY OF THE DISEASE.

The mosaic disease of sugar cane, the presence of which has recently been discovered in Louisiana and other Southern States, is the malady that in epidemic form has occasioned severe losses in parts of Porto Rico during the past four years. There it has been variously called matizado, "mottlings;" rayas amarillas, "yellow stripe;" morida de perro, "dog bite;" la enfermadad de Arecibo, "disease of Arecibo;" la enfermadad nueva, "new disease;" etc. The disease was first noticed in Porto Rico about the middle of 1916.

Starting from some point near Arecibo, on the north coast of Porto Rico, it spread rapidly over the cane fields to the west, down the west coast to the south coast, and up into the valleys and hills

of transmission was not present or at least not abundant in this region, it has spread very little. At Santiago de las Vegas it was found on plants recently imported from Louisiana and from Tucuman, Argentina. The latter plants had come originally from Java. The disease had spread from these plants to an adjoining field of the native Crystalina cane. In view of this demonstration of its ability to spread at Santiago, it is very fortunate that the diseased plants were early observed and destroyed. A slight infection has been found at Mercedes, also as the result of a recent importation.

Infected cuttings have been received in both Porto Rico and Cuba from Tucuman, Argentina, but to what extent the disease is prevalent in Argentina has not been learned.

Last year the mosaic disease was found in abundance at La Romana and the city of Santo Domingo, Santo Domingo, and less plentifully at Samana, La Vega, Monte Cristi, and Bonao.[1] Lastly it was discovered at St. Croix, Virgin Islands, on cane imported from Porto Rico.[1]

DISTRIBUTION IN THE UNITED STATES.[2]

The presence of the mosaic disease in the United States was first suspected when an agent of the Office of Sugar-Plant Investigations of the United States Department of Agriculture discovered young diseased cane in Porto Rico from seed cane imported from Louisiana. The plants were so young at the time that secondary infection seemed improbable, and it was assumed that the seed pieces were diseased when shipped from Louisiana. Accordingly another agent of the same office visited Louisiana and on July 7, 1919, confirmed the presence of mosaic there. The State authorities were apprised of this important disclosure, and the Government agent made a hurried reconnoissance of the Gulf States, which revealed the fact that the disease was already quite widely distributed there.

On account of the infectious nature of the malady and the fact that it has caused severe losses in other cane countries, a complete survey of the Southern States was immediately instituted to determine the location of all infested areas and, if possible, to trace the original importation of the disease and the course of its subsequent spread. Infested areas have been well delimited. The disease has been found by inspectors of the United States Department of Agriculture in Louisiana, Florida, Georgia, Alabama, and Mississippi (fig. 1). It is most abundant in Louisiana, as would be expected. There the river district is already badly infested. As far north as Angola, in West Feliciana Parish, several fields in a large plantation were found

[1] Stevenson, John A. The mottling disease of sugar cane. *In* Jour. Dept. Agr. and Labor, Porto Rico in press).

[2] Thanks are due to Mr. W. G. Taggart, vice director of the University of Louisiana Sugar Cane Experiment Station, and to Dr. C. W. Edgerton, pathologist, Louisiana Experiment Station, for courtesies extended to the writer and suggestions facilitating the survey in Louisiana.

in which 75 per cent or more of the plants had the mosaic disease. From this point south to Donaldsonville, however, the amount of infection is not heavy. Many plantations are entirely free from mosaic, so far as can be determined by inspection. From Donaldsonville to New Orleans an increasing amount of infection was recorded by the inspectors. Between Lutcher and Reserve, about 75 per cent of the plants in every plantation were infected. This is by far the most heavily infested large area in the United States. From this region to New Orleans and from New Orleans to the lower extremity of the river district the amount of infection ranges from 4 to 30 per cent. Just a few fields were visited where no mosaic was found.

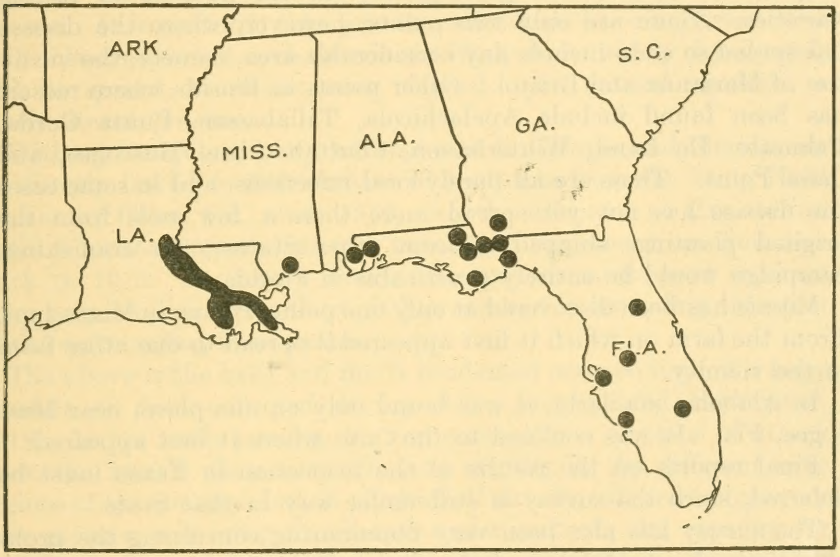


FIG. 1.—Map showing the location of diseased areas of sugar cane in the United States.

In the Bayou Lafourche district mosaic was found in only about one out of four fields visited and where present amounted to only 1 to 8 per cent of the plants. In the Bayou Teche district no mosaic was found on plantation cane, although nearly 500 fields were carefully inspected. A few cases were found in this region on cane recently distributed by the State Sugar Experiment Station. The immediate destruction of these few sources of infection is a matter of great importance. No mosaic whatever was found west of Bayou Teche or in Avoyelles and Rapides Parishes to the north. Thus, a very considerable part of the sugar-cane lands of Louisiana is still free from the disease, and every effort should be made to keep it free.

In Georgia the worst infested region is in the vicinity of Cairo, Grady County. There the proportion of infection ranges from less than 1 to 75 per cent or more in fields where the disease is present,

but only about one-fourth of the cane fields in this county harbor the infection at all. The affected area is quite sharply delimited, all of the disease being confined at present to farms located on the highways leading out from Cairo. The cane fields in Georgia consist usually of a few acres grown for sirup making. It is quite possible that by prompt and energetic action this community could free itself from the mosaic disease in short order.

Cane fields are distributed over practically the whole State of Florida, but the crop is grown largely for sirup for home use and the cane patches are even smaller than those in Georgia. Mosaic has been widely scattered over the State by the distribution of cuttings from experimental plats grown for the purpose of testing varieties. There are only two points, however, where the disease has spread so as to include any considerable area, namely, the vicinities of Marianna and Bristol. Other points in Florida where mosaic has been found include Apalachicola, Tallahassee, Punta Gorda, Palmetto, De Land, Winterhaven, Chattahoochee, Muscogee, and Canal Point. These are all purely local infections, and in some cases the disease has not yet spread more than a few rods from the original plantings shipped in from other States. An eradication campaign would be entirely practicable in Florida.

Mosaic has been discovered at only one point, Biloxi, in Mississippi. From the farm on which it first appeared it spread to one other farm in the vicinity.

In Alabama similarly, it was found only on one place, near Muscogee, Fla. It was confined to the farm where it first appeared.

Final reports on the results of the inspection in Texas must be deferred, since the survey is still under way in that State.

The survey has also been very illuminating concerning the probable time of introduction of the disease into this country and the method of its subsequent spread here. Since 1913 a prohibitory regulation has been placed upon the introduction of sugar cane into the continental United States, and it is probable that no cane has been introduced since that time. Prior to 1913 varieties of sugar cane were imported many times by private individuals and by various Government agencies. The Sugar Experiment Station of the Louisiana State University, at Audubon Park, has been particularly active in importing new varieties, with the idea of securing some higher in sugar content and yield than those already grown here. Whether the mosaic was introduced by the experiment station or by private individuals no particular blame attaches to those who are responsible for the importation of this obscure disease. There is no known method by which the presence of the disease in cuttings can be positively established. It is merely pointed out that such an importation would be practically impossible with the present quarantine against

sugar cane. Concerning the probable time of the importation that was responsible for the present wide distribution of mosaic in America, the survey has brought out the fact that the distribution of cuttings by the Louisiana Sugar Experiment Station in 1914 and prior to that time has not resulted in establishing the disease at the points where such cane was received. Since 1914, however, every point receiving seed from the station has become the center of a larger or smaller infected area. The inference, of course, is that while the disease may have been present at the station for a few years prior to 1914, it had not become so widespread that every seed shipment from there contained some infected cuttings. At the present time, about 97 per cent of the cane plants at the station have the mosaic disease. It is probable that private individuals have imported cane with this disease, but such cane is not likely to be widely distributed, and its spread, therefore, must depend upon natural agencies, a much slower process.

Without exception, every infested area in Georgia and Florida can be directly traced to distributions of seed cane from the Sirup Field Station at Cairo, Ga., since 1916, and the infection at this station dates from the importation of a number of varieties from Audubon Park in 1915. In nearly every instance where diseased cuttings have been received from Cairo, it has resulted in secondary infection of the surrounding native cane.

The above is the brief and much condensed compendium of a large amount of data collected during July, August, and September, 1919. It has made possible the recommendation of plans of attack upon the mosaic disease, which vary slightly in the different cane regions of the country, but all of which, if strictly adhered to by every cane planter, will bring the disease under control. Its capacity for rapid spread, as demonstrated in Georgia and Florida, means that a lapse of one year will result in immeasurably complicating the problem of ultimate eradication.

LOSSES IN THE UNITED STATES.

Since the mosaic disease had been unrecognized in this country until the writer announced its presence in July of this year, no extensive data have been accumulated to determine whether the losses caused by it in the United States are comparable with those sustained in Porto Rico. A few figures (Table II) have been obtained in Louisiana, however, which indicate that we may expect a decrease in yield almost equal to that in Porto Rico if the disease is permitted to become as widespread here as it is in that country. Losses here are held in check somewhat on account of frequent replanting. It has been noticed that where infected sugar cane is allowed to ratoon over a long period of years that losses due to the mosaic are more severe

each successive year. The figures in Table II were obtained by cutting all of the cane in approximately square patches of about one-tenth to one-fifth of an acre selected in commercial fields and in the fields at the Sugar Experiment Station, Audubon Park, La. The stalks cut from such patches were then sorted into two classes, diseased and healthy, and the average weight of stalks in each class was determined. The patches were not selected at random, but an attempt was made to find areas where the mosaic was doing a maximum amount of damage and at the same time a sufficient number of healthy plants were present in the patches, growing under identical conditions, in order to make a fair comparison possible. Since, if no attempt is made to control the disease in these fields, we may expect ultimately to find an infection of 100 per cent, the losses will then be equivalent to the figures found in column 5 of Table II.

TABLE II.—*Tests of sugar cane in Louisiana, showing the extent of losses in different varieties.*

Variety.	Number of stalks—		Average weight of stalks—		Reduction in weight of diseased stalks.	Diseased stalks in field.	Loss in tonnage.
	Healthy.	Diseased.	Healthy.	Diseased.			
			Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
Louisiana Purple	330	160	1.13	0.7	38	32	12.16
Louisiana Striped	268	100	1.507	1.22	19	27	5.13
D–74	204	108	1.27	1.03	18	34	6.12
D–95	348	136	1.65	1.16	29	28	8.12
L–511	373	310	.874	.787	10	45	4.5

PRIMARY SYMPTOMS.

Upon walking between the rows of cane in an affected field, more or less plants will be seen that are conspicuous on account of a general pallor of the leaves. This may be discernible for many rods. Closer examination of such plants reveals that the pallor is due to irregular light-colored streaks or spots on the leaves. The affected leaf areas, in so far as color is concerned, are of two distinct types. The most common type presents merely a "washed-out" appearance. It is, in fact, merely a tint of the normal color, in which the blue and yellow are present in the same proportions but diluted. In the second type, the yellow is predominant, and the affected areas have a decided yellowish green appearance. The normal and affected areas are sharply demarked. In other words, there is no gradual merging of one color into the other. There is a great diversity of patterns in the different varieties, due to the variation in the amount, size, and shape of the light-colored areas, but the arrangement is so constant in any particular kind of cane that the character could be used as an aid in determining varieties.

Among the cane varieties commonly grown in Louisiana and other Southern States, some rather constant differences occur in the expression of the mosaic disease. In L 511 it will be noticed that streaks are rather scant in newly invaded leaves and on account of their light color make a great contrast with the normal areas. They are bluntly pointed and range from one-sixteenth to three-sixteenths of an inch wide and from one-fourth of an inch to 3 or 4 inches long (Pl. I, fig. 4). Later, the light areas or streaks are more numerous and in most cases tend to become confluent in well-defined bands of light tissue extending across the leaf at right angles to the midrib and alternating with bands where the light streaks remain isolated. These bands are from 1½ to 2 inches long. The above condition is typical of the disease as it appears in L 511, but does not invariably occur.

In D 74 the streaks are not usually isolated, even at first, so that very quickly the coalesced light areas are predominant and the normal areas appear as irregular, elongated islands 1 thirty-second to three-eighths of an inch wide and of varying length, from one-fourth of an inch to several inches, as shown in Plate I, fig. 5. Affected areas are light green at first, but the tendency for the whole leaf to become opaque yellow is pronounced.

In purple cane the light areas are elongate and isolated at first, but later they predominate and coalesce and the normal green shows as irregular elongated islands, as illustrated in Plate I, fig. 5. The islands are not of uniform width or length.

In the youngest leaves of Ribbon cane, the light areas are in the shape of attenuated streaks, usually about one-eighth of an inch wide and one-half of an inch to 1½ inches long, but the size varies greatly, some streaks being very minute, and others, by running together at the ends, form continuous stripes 6 inches or more in length. In general, the streaks are isolated from one another and uniformly distributed on the leaf blade as in Plate I, fig. 4. The amount of normal-colored tissue greatly exceeds the light tissue at this time. Exceptionally, the light streaks may be confluent from the first, and this is more frequently seen near the midrib, leaving the margin normal in color or with a few scattered pale streaks. In slightly older leaves, by growth and confluence of the light-colored areas the latter becomes predominant and the whole leaf becomes pallid or even yellow in its general appearance. The dark-green or normal areas are now very scant, and they appear as elongated streaks in the pale green, just the reverse of the condition in young leaves, except that the dark-green streaks are less regular in outline. The individual streaks vary considerably in width and direction throughout their extent, streaks perhaps three-eighths of an inch wide at one end becoming constricted to 1 thirty-second of an inch, then alternately widening and narrowing or becoming oblique with the midrib, with no apparent forces

limiting their extent or direction except that in general they are elongated in the direction of the parallel veins of the leaf.

In D 95 the light areas are predominant from the start (Pl. I, fig. 5).

In L 219 the light streaks are isolated near the base of the leaf but become confluent toward the tip.

In L 226 the streaks are isolated and even in older leaves remain so.

L 231 is very severely injured. The leaves are usually quite yellow, as shown in Plate I, fig. 6. Practically the entire surface is light from the beginning. There are exceptions, however. The amount of injury in this variety is variable.

L 253 is quite tolerant. The lighter areas predominate but are not yellowish. All plants seen were dark green and vigorous.

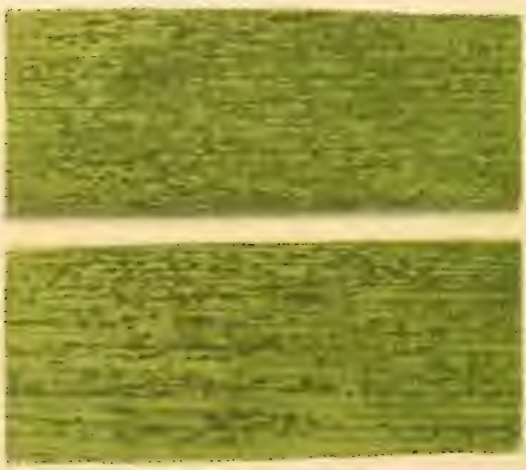
SECONDARY SYMPTOMS.

Field observations covering a number of years indicate that the deleterious effects of the mosaic disease are cumulative. The streaking and spotting of the leaves discussed above are the only noticeable sign in newly infected plants. The disease is never fatal during the first year and, in fact, it rarely terminates in death even in diseased plants that have been allowed to ratoon for years. Usually, however, more serious effects are seen in first ratoons of cane which became infected the previous year or in plant cane originating from diseased cuttings. At this time another quite distinct leaf symptom appears. It consists of small white opaque spots and streaks in the light-colored areas. These streaks are smaller than the light areas previously mentioned and differ from them in having no pigment whatever. They range from mere points to elongated irregular streaks several inches in length. The white streaks may become confluent to a limited extent. They are for the most part restricted to the light-green areas of affected leaves, but do not correspond to them in outline and typically remain more or less isolated from one another. The white opaque tissue has a dried-out appearance and seems to be quite functionless. It remains firm, however, and does not become brown or rot out. The amount of total leaf area occupied by this type of tissue rarely exceeds 20 to 30 per cent of the whole.

At about the same time, or during the next year, a still more injurious sign of mosaic appears, namely, the striping or cankering of the stalk. This is much more marked in some varieties than in others. Ordinarily, it does not become noticeable until the cane is quite well developed. By tearing away the enveloping leaf bases, cankers can sometimes be found in the incipient stage. They appear as discolored or water-soaked patches or longitudinal streaks on the internodes. In severe cases these areas become sunken and the internodes are spindle shaped and attenuated. Longitudinal cracks may appear, resulting in the drying out of the cane. There is a tendency toward shortening of the joints and premature development

1.—A short piece of healthy leaf of the immune variety Kavangire.

2.—A piece of leaf of variety B-3922, showing isolated, more or less rounded and irregular patches of normal color on a background of pallid, affected tissue.



3.—A piece of leaf of variety D-117, showing a mosaic pattern somewhat similar to the above, but finer.

CANE AND OTHER GRASSES.

4.—A common type of mosaic, irregular streaks of pallid green, of unequal length and width but elongated in the direction of the long axis of the leaf, on a background of normal green; on leaf of variety Rayada.

5.—A pattern somewhat similar to the above, but with the colors reversed, so that the pallid green predominates; on leaf of variety G. C. 1479.

6.—The most injurious of the common types of mosaic. Just a few streaks or islands of normal green remain on a background of yellowish green; on leaf of variety M. P. R. 2.

A. HOEN & CO. PHOTO-LITHO.

of roots and shoots at the nodes of standing cane. Figure 2 shows such a condition in Yellow Caledonia cane. The photograph reproduced here was taken at Arecibo, Porto Rico, in 1919, and the probabilities are that the plant had been infected for at least five years. These identical cuttings and similar ones were brought to Washington and planted in a quarantine greenhouse. Most of them grew, but at the present time, five months after planting, they are scarcely 1 foot tall. The opaque white streaking covers practically all of the leaf area. This is the most excessive injury ever observed by the writer. Most varieties of cane do not go to pieces like this, but rather the injury to stalks consists merely of retarded development. Among the well-known varieties, however, all gradations in the extent of injury between these two extremes are to be found.

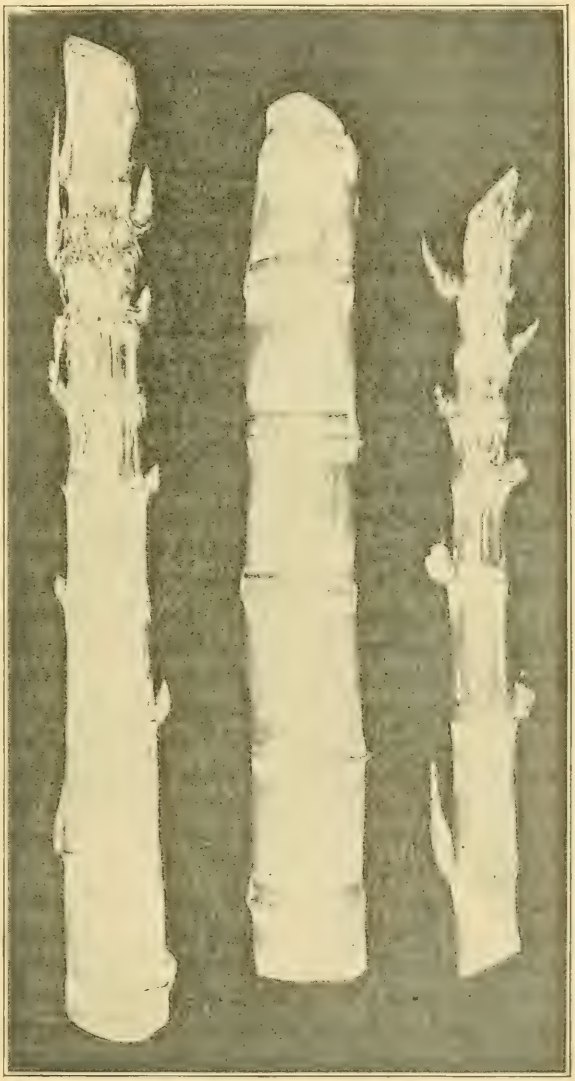


FIG. 2.—Canker stage in Yellow Caledonia sugar cane; healthy cane of the same variety in center.

When a large proportion of the plants in a field are infested, the aspect in general resembles the effect of a severe drought. The foliage of the entire field is yellowish, and the plants are more or less noticeably stunted. Where a row of some immune variety is planted in or near a badly infested field, the contrast in color is exceedingly conspicuous and the dwarfed habit of infected plants is more notice-

able. It is possible to recognize such fields from a distance of half a mile or more on account of their sickly, dry appearance.

INJURIES RESEMBLING MOSAIC.

Many types of injury are commonly found on cane leaves that might be confused with this malady by one not familiar with it. The condition termed chlorosis, which is due for the most part to soil conditions, expresses itself in many ways, some of which closely simulate the mosaic disease. The affected areas are white opaque or yellow, and the most familiar form is a regular striping of the leaves longitudinally. The stripes usually extend the entire length of the leaves and may be about one-eighth of an inch wide and numerous, with normal green stripes of equal width spaced between them, or the chlorotic areas may be quite wide. Occasionally, the entire leaf is pure white. Less frequently the areas are in the form of large spots or blotches, extending inward from the margins of leaves or situated at the center of the blades anywhere from base to tip. Another type, which is rare, consists of a very fine irregular white mottling of the leaves, which, however, is in local patches and does not involve the whole leaf, as is invariably the case with the mosaic disease. Many fungi cause spotting of the leaves of cane, but these can easily be distinguished, as the spots usually turn brown and the leaf tissue dies, which does not occur in the cane mosaic. Since a pale-green halo is sometimes present surrounding these small spots, they have the appearance of mosaic from a distance, especially when quite numerous, but a close examination always reveals quite distinct differences. Many insects, especially those which feed by puncturing the leaf epidermis and sucking the sap from the layers of cells below, cause a very fine mottling of the leaves when the punctures are present in enormous numbers. Ordinarily, the punctures are scattered and can lead to no confusion. This type of injury can also be determined by close inspection, since the minute pale area surrounding each individual puncture is almost exactly circular and has no tendency to elongation in the direction of the long axis of the leaf, such as is almost invariably the case in true mosaic. Drought, lack of proper nutrients in the soil, excessive rainfall, and poor tilth, or combinations of these, sometimes result in a general pallor or yellowing of the leaves, but this color is always uniform and can lead to no confusion.

VARIETAL SUSCEPTIBILITY.

VARIETIES ATTACKED.

More than a thousand varieties of cane have been determined to be susceptible to the mosaic disease. Most of these are the progeny of seedling canes that exist in small variety-test rows or patches at the

various sugar-cane experiment stations, but the list includes also practically all of the commercially esteemed sorts grown for the mills on a plantation scale.

So far as can be learned, none of the varieties grown in Java is truly immune, but a high degree of resistance or tolerance of the disease has been observed in the favorite Java seedling canes grown in Porto Rico, a probable explanation of which has already been given. Only Java 56, 100, 228, and 234 have been seen by the writer in Porto Rico, but all of these, though 100 per cent of the individuals were affected, made a thrifty growth and produced apparently normal stalks. The leaves are not noticeably yellowed, but on the contrary appear to be of uniform dark-green color when viewed from a distance. Close inspection, however, shows the characteristic streaks, but the diseased areas are very little lighter than the normal areas. Probably the damage done to an individual plant is slight, but the aggregate damage to all of the individuals in a field is a measurable quantity and has been shown to be quite considerable in Java. In the different varieties all degrees of tolerance are exhibited, ranging from the highly resistant Java canes down to the soft white Otaheite or Bourbon cane, which is so severely injured that the cane is hardly worth milling. In addition to the conditions which might be termed varietal tolerance of the disease, some varieties exhibit decided and rather constant differences in the percentage of individuals that become affected under the same conditions. This is brought out in variety-row tests where the same varieties have been planted at several points in the same field. Under these conditions it has been found that some varieties will show a 100 per cent infection of the individuals in all of the rows, while in others perhaps only 60 per cent of the plants will be diseased in each of the separated rows or plats. It seems reasonable to suppose that all varieties were equally exposed to the contagion in such situations. This fact indicates a possibility of resistant strains among the individuals of a variety.

The Rayada or Striped cane and the Crystalina or White Transparent, the two favorite varieties in Porto Rico, are severely injured. Yellow Caledonia is grown on a large scale in some localities, and plants of this variety killed by the mosaic disease have been observed. This is quite unusual, since attacked plants of most varieties become badly stunted but do not die. All seedling canes from Demerara and Barbados grown in Porto Rico are attacked. Seedlings of the Insular and Federal agricultural experiment stations likewise are all affected, as are the seedlings originated at Centrals Guanica and Fajardo. Among the varieties planted commercially to a limited extent the Bambu, Cavengerie, Morada, and, in fact, all the broad-leaved canes have proved to be susceptible.

In Cuba all varieties that are exposed seem to become infected, but since the disease has not become rampant nor spread over any considerable area no opportunity to observe the reaction of all the varieties grown there is to be had. Practically all of the seedlings originated in the Harvard Experiment Station near Cienfuegos were affected, as well as the imported Java 228, L 511, and the native Crystalina at Santiago de las Vegas.

Practically all varieties are attacked in the Hawaiian Islands, and extensive damage is done.

The common varieties in Louisiana have proved susceptible to mosaic disease. Louisiana Purple, Louisiana Striped, D 74, D 95, L 511, L 218, L 219, L 226, L 231, L 253, and hundreds of seedlings being tested at the Louisiana Sugar Experiment Station all fall prey to the ravages of this disease.

IMMUNE VARIETIES.

Fortunately a few varieties of sugar cane have been discovered which appear to be entirely immune. Most of them are of the slender North India type, generally known as Japanese canes. The Kavangire, a variety which, because of its prolific stooling, yields a very large tonnage and is much esteemed in Argentina for making sugar has never been observed to be diseased, although it has been exposed to infection for four years in the worst infested regions of Porto Rico.[1] It is a rather long season cane, however, and for this reason is probably not suited to Louisiana conditions. Another Japanese cane, Cayana 10, which is becoming prominent in the sirup sections of Georgia and Florida, is also immune. This variety has already met with considerable favor on the part of cane growers in Georgia. All the other Japanese varieties observed, including many imported by the Office of Foreign Seed and Plant Introduction of the Bureau of Plant Industry, have been found to be uniformly free from this disease.

Among the broad-leaved thicker stalked varieties several kinds have been found that appear to be immune, but our evidence of their immunity is not so complete as is the case with the Japanese varieties. Louisiana seedlings 1646, 1606, 1674, and 1797, growing in the variety test plats at Audubon Park, New Orleans, this year appeared to be immune. No individuals of these varieties were diseased, although they were surrounded by other varieties, the individuals of which averaged 97 per cent diseased.

[1] Townsend, C. O. An immune variety of cane. (Abstract of an article by F. S. Earle.) *In* Science, n. s., v. 49, no. 1272, p. 470–472. 1919.

OTHER HOSTS.

A number of other grass plants are known to be subject to the mosaic disease, but apparently they are attacked with difficulty and only under conditions favorable to the disease. Among these hosts are corn, sorghum, rice, millet, crab-grass, foxtail, and Panicum. Probably the list of susceptible plants is much larger, but up to the present time opportunity for testing others has not been had. In the case of corn, rice, and millet, we have no experimental proof that the diseases are the same, but must depend upon field observations. If not the same, the disease must be very similar, since the leaf symptoms are identical. The characteristic streaked and spotted appearance of the leaves is present in all attacked plants.

With regard to sorghum, crab-grass, foxtail, and Panicum our evidence is conclusive and proves that the infectious material or virus is the same for all of these plants. Sorghum seed of the Early Amber, Sugar Drip, and Japanese Ribbon varieties was sown in a bed at the quarantine greenhouse at Washington, where diseased plants of 17 different varieties of sugar cane were growing. When the sorghum plants were about half grown, practically all of them began to produce mottled leaves and continued to do so until they went to seed.

The seed was saved from these sorghum plants to determine whether the disease is transmitted to the next generation in the true seed.[1] The leaf symptoms in these greenhouse plants were exactly like the symptoms on sugar-cane leaves. Plants arising from the same batch of seed used in the greenhouse experiment cited above but planted elsewhere and not exposed to the disease did not show the phenomenon but produced healthy leaves of uniform color. The crab-grass, foxtail, and Panicum came up as volunteer plants in the quarantine greenhouse. Scores of stools of these weeds were allowed to mature for observation and identification. Every plant became infected and exhibited the typical leaf symptoms. Some half dozen other species of wild grasses were present in the greenhouse, but they were not attacked. All of the wild grasses were abundant outside of the greenhouse, but in spite of an assiduous search in the vicinity not a single infected plant could be found. The conclusion to be drawn from these observations is obvious. We are not dealing with similar mosaic diseases of these various graminicolous hosts, the viruses of which are specific for each host, but with one and the same disease.

The existence of other host plants, especially the common wild grasses, would appear to be one of the most alarming of the recent developments in the problem. It is needless to say that the control

[1] This seed was planted in flats. At the present time, three weeks after germination, no sign of the mosaic has appeared.

of the disease would be immeasurably complicated if it were to become prevalent on such omnipresent weeds. Fortunately, however, our observations appear to indicate that the grasses other than cane become infected only under conditions favorable to the disease and in the near vicinity of infected sugar-cane plants. Infected corn, for instance, has been seen by the writer only in Porto Rico, where it was growing between the rows of diseased cane stubble. Infected rice plants were observed there only once, growing just across a narrow dirt road from a badly attacked cane field. At Audubon Park, La., attacked sorghum was seen in a similar situation, the most remote plants being only about 3 rods from the cane, and the percentage of attacked plants decreased in an inverse ratio to the distance from the cane. The same was true of crab-grass, which was abundant in the sorghum field. These observations are encouraging and tend to offset the disconcerting facts discussed above.

NATURE OF THE DISEASE.

INFECTION PHENOMENA.

Sugar-cane mosaic is an infectious chlorosis, similar in many respects to the mosaic diseases of tobacco, cucumber, bean, tomato, and potato. Evidence of its infectious nature exists in hundreds of field observations and in the infection of experimental plants under controlled conditions. The well-defined epidemic in Porto Rico, in which it has been established that the disease started in a small local area and gradually spread from this focus of infection, diseased plants being confined within the limits of the ever-increasing infested territory and not appearing sporadically at remote points, is convincing. It leads to the inevitable conclusion that some virus or inoculum is responsible for the appearance of new cases and that the only source of inoculum is some plant previously infected with the disease. No other explanation accounts satisfactorily for the observed facts. Climatic conditions were at first suggested, but the epidemic has lasted already for a period of years, during which rainfall, temperature, sunshine, and the other factors that go to make up climate have been normal. The wearing out of soils was regarded as a possible cause, but during the steady progress of the disease it gradually encroached upon every conceivable type of soil, including the richest and most productive in the island. Strong support was given to the idea that it was a case of deterioration or the "running out" of varieties, but when it became evident that all varieties present in the invaded district were affected, this idea was abandoned. For the same reason the hypothesis that it is a case of bud variations, or "sports," seems highly improbable, and when the regular progress of the epidemic is borne in mind, radiating outward

as it does from a common starting point, there is seen to be nothing to substantiate this claim.

Only a few specific observations of infection may be cited in the limited space available. In October, 1918, healthy seed of about 80 varieties was brought into the infested area from disease-free regions in order to determine whether any natural immunity existed among the varieties present in Porto Rico. This seed was planted at the Santa Rita estate, near Yauco. When the seed germinated, the young plants were seen to be healthy and normal, but within six weeks to two months practically every plant of all varieties with one exception (the Japanese Kavangire) showed the unmistakable symptoms of mosaic. This was a clear case of secondary infection from the fields of diseased cane surrounding the test plat.

At Santiago de las Vegas, Cuba, about 200 seed pieces of Java 228 cane imported from Tucuman, Argentina, were planted in two rows, and two rows of the native Crystalina cane were planted beside them. The Java cane was 100 per cent infected when it came up, the cuttings having come from diseased parent plants. When this planting was examined in June, 1919, 75 per cent of the Crystalina plants were characteristically diseased. The Crystalina seed pieces had come from a field which was minutely searched and found to be entirely free from disease. No other cases were found in the entire region, in fact, with the exception of a single stool of L 511 imported from Louisiana.

In July, 1919, a field of D 74 stubble cane, grown for sirup near Cairo, Ga., was found to be healthy with the exception of one corner near the kitchen garden, where about 80 per cent of the plants had the mosaic. Investigation revealed the fact that a patch of green chewing cane had been growing adjacent to the D 74 at that corner during the preceding year. The green cane was found growing elsewhere on the farm this year, and examination showed that every plant had the mosaic disease. Clearly the D 74 had become infected last year, the disease had survived the winter in the stubble, and the shoots were diseased when they appeared again.

At Washington, D. C., 17 varieties of cane, all diseased, are growing in an insect-proof quarantine greenhouse.[1] From time to time healthy sugar-cane plants in pots have been taken into the greenhouse and left exposed to the contagion. Invariably they show the incipient symptoms of the disease on the average in 17 days, proving that the incubation period is from two to three weeks. As has been mentioned elsewhere, sorghum and wild grasses taken into this greenhouse have also become infected. Much more evidence of this kind could be adduced, but it is believed to be sufficiently clear that infection

[1] Insects were present in the greenhouse.

by some principle present only in diseased plants is responsible for the appearance of the disease in formerly healthy individuals.

TRANSMISSION OF MOSAIC IN DISEASED SEED PIECES.

Experiments in Porto Rico [1] and elsewhere have repeatedly demonstrated that cuttings from infected stalks invariably give rise to infected plants. The young shoots are seen to be mottled as soon as they appear. These are referred to as primary infections. The fact is one of far-reaching importance, and to it must be attributed the spread of the disease to new regions, remote from any infected cane, by shipments of cane seed. The use of diseased stalks for propagating results in wider distribution of diseased plants on the same plantation from year to year and insures the survival of the virus, even in the absence of secondary infections. Transmission of the disease in cuttings is a fact, the importance of which can not be overemphasized in view of its obvious bearing on control measures.

TRANSMISSION OF THE DISEASE BY CARRIERS.

It can be proved mathematically that by the law of chance the percentage of diseased plants in a plantation would tend to remain stationary from year to year provided there was no conscious or unconscious selection,[2] if the spread of the disease depended wholly upon the use of infected cuttings. Nature has provided a far more efficient method for the quick dissemination of the malady. Secondary infection, i. e., infection due to the inoculation of healthy plants during the growing season, goes on at a more or less rapid rate wherever the disease has been observed. Secondary infections are easily determined as such when the plants are young. In the case of plants infected in the greenhouse it has been determined that only the leaves which were immature at the time of inoculation and leaves subsequently formed become mottled. When a plant is found with normal leaves up to a certain point on the stalk and mottled leaves above that point it is a clear case of secondary infection. Since in older plants the lower leaves are gradually sloughed off until only a relatively small terminal tuft of the youngest leaves remain when the plant approaches maturity, this method is obviously limited to young plants or to plants with green leaves still present above and below the point of inoculation.

The rate of spread of the disease, as indicated by these secondary infections, varies greatly. Fields are frequently seen in which there has been apparently no secondary infection during an entire growing

[1] Stevenson, John A. The "mottling" disease of cane. Porto Rico Insular Exp. Sta. Ann. Rpt. 1916–17, p. 40–77. 1917. [Literature], p. 76–77.

[2] Selection is employed where the disease is not recognized. During the beginning of the epidemic in Porto Rico, when sugar was bringing an unprecendented price, it was learned that the manager of one of the mills was instructed to grind the best cane and save the poorest for seed. The "poorest" was undoubtedly that attacked by mosiac.

season. As an extreme case illustrating this point, the fields near Cienfuegos, Cuba, may be cited. There the disease has merely survived by the planting of infected seed pieces, and secondary infection, if it goes on at all, is certainly very limited. Even in Porto Rico, during the height of the epidemic, secondary infection was at a standstill in some localities for a year or more. On the contrary, whole fields of healthy cane became infected in the short space of a month or two. Such a case was the invasion of the variety test field at Santa Rita, Porto Rico, previously mentioned. No doubt the explanation for this great variation in rate of spread by secondary infection must be sought in the mechanics of inoculation. Up to the present no positive proof of the method by which inoculation is accomplished in nature has been brought forward. Reasoning from the fact that new cases often appear at some distance from diseased individuals, it would seem that some agent or carrier is necessary. Mere contact of diseased and healthy plants does not serve to communicate the infection from the former to the latter. In no case has the planting of healthy cuttings in the same pots with diseased plants resulted in the new plants becoming diseased. The same holds true for plants in the field, where healthy plants are often seen with their leaves mingling freely with the leaves of diseased plants for a time much longer than the incubation period for mosaic, but with no evidence of transference of the inoculum. It is evident that special conditions are necessary in order that the disease can be communicated to healthy plants.

Field observations indicate that acceleration in the spread of the mosaic disease is accompanied with or preceded by severe insect infestations. The cane leafhopper (*Tettigonia* sp.) in particular has been noticed to accompany the rapid spreading of the disease. This evidence is incomplete, but it is supported by the fact that 10 healthy plants placed in insect-proof cages in the greenhouse at Garrett Park, Md., did not contract the disease, while five control plants outside of the cages, but otherwise under identical conditions, all became infected. Aphids were abundant on the diseased cane in this greenhouse, and a few leafhoppers were present. A great deal of experimental work remains to be done before formal proof of the responsibility of any particular insect or insects for the transmission of the disease can be offered.

SOIL RELATIONS.

There has been no indication that the contagion persists in the soil after a crop has been removed and the stubble plowed up. Fields that have been veritable hotbeds of infection after being plowed up and planted with clean seed have only a few scattered cases, which can be accounted for by faulty seed selection. Healthy cuttings planted in the soil of pots from which badly diseased specimens had

just been removed grew without any evidence of the disease. The virus does not live over in the soil and it is doubtful whether it exists there at any time. In this respect the mosaic does not by any means present the practical difficulties in the way of control measures to be met with in root-rot. Root-rot, in fact, is to be regarded as a far more serious problem for the Louisiana cane planter than mosaic on this account.

RELATION TO DISINFECTANTS.

Treatment of infected seed pieces by soaking in strong Bordeaux mixture or corrosive sublimate previous to planting has had no effect on the course of the disease. All shoots were typically mottled as soon as they appeared. It was hardly to be expected that superficial disinfection could influence the virility of the infectious principle when all our evidence indicates that the latter permeates the internal tissues, or at least the vascular systems of affected plants.

RELATION TO FERTILIZERS.

Many experiments [1] have been performed in Porto Rico to determine the effect of applying fertilizers, since the claim was made by many planters that mosaic was due to insufficiency of plant nutrients in the soil. Filter press cake, sulphate of ammonia, and lime in various combinations, together with turning under cover crops and good tilth, had no noticeable effect on the disease as compared with control plats. Standard complete fertilizers were also tried. Beyond a slight stimulation in growth and the darker green color of the treated plants, there was no observed effect. Diseased plants may be expected to respond to good growing conditions the same as healthy ones, but the same constant difference between healthy and diseased plants is maintained under all conditions. The diseased stalks remain below the average weight for healthy stalks and are just as capable of spreading the disease. Liming the soil has no more effect on diseased plants than the application of fertilizers.

CONTROL.

It is interesting to note that in Java long experience has demonstrated that the disease can best be held in check by careful selection of healthy plants for seed and by replanting fields with cuttings taken from the same field, in preference to buying cuttings of unknown origin or moving the cuttings from field to field on the same plantation. The use of such methods practically amounts to tacit admission of the infectious nature of cane mosaic, although it is ascribed to "bud variation." The facts which have most impressed the Dutch planters are that cuttings from diseased stalks always

[1] Stevenson, John A. The "mottling" disease of cane. Porto Rico Insular Exp. Sta. Ann. Rpt., 1916–17, p. 40–77, 1917. [Literature] p. 76–77.

produce diseased plants and that careless importation of seed is apt to result in increased amounts of the disease.

In the Hawaiian Islands also the disease is controlled by selection of clean seed and the use of resistant varieties.

Measures for controlling the mosaic disease recommended in the following pages are not haphazard expedients, but have been used with very satisfactory results in Porto Rico for more than a year. Planters there have paid a heavy price to learn them, and it is urged that planters of sugar cane in the United States cooperate to prevent a possible epidemic. Indifference to the situation may result in the cane growers being confronted with the fact that it is too late to practice seed selection, as is already the case in western Porto Rico. At present, it will work no particular hardship on the planters to take steps that will reduce the disease to a minimum.

ELIMINATION BY ROGUING.

Roguing consists of pulling out infected plants, root, stem, and branch, and throwing them down between the rows. It is based on the fact that as soon as the plants are wilted they are no longer dangerous as a source of infection. This method is applicable only to fields in which the disease has not obtained a strong foothold. It is not recommended for fields in which the number of infected plants exceeds 5 per cent in half-grown to mature cane or 20 per cent in young plants just sprouting. The size of the field and the condition of surrounding fields with reference to the occurrence of the disease in them must also be taken into consideration. When the field is quite small or consists merely of a few rows or plants of a new variety being propagated for trial on a plantation scale, it should be rogued even if 100 per cent of the plants are infected. Such plants are a constant menace to plants in surrounding fields. In large fields where the proportion of diseased individuals is greater than 20 per cent, roguing is impracticable, not because the plants are any less potent as sources of infection, but because diseased plants produce millable cane, and to destroy considerable quantities of such plants would probably result in greater financial loss than would be sustained by the reduction in yield due to new cases. Large fields with a high percentage of diseased plants should be allowed to mature, but no cane from such fields should be saved for seed.

It is suggested that the following schedule of inspections and roguing be put into operation: In the spring, just as soon as all of the plants have sprouted, the fields should be inspected by passing up and down the rows. All diseased stools should be pulled out of the ground and cast down between the rows. If this first inspection is carried out in a thorough manner the field will be completely freed from the disease provided no secondary infections are going on.

Since there are as yet no certain means of determining the latter fact, a second inspection is essential. It should be made from 25 to 30 days after the first, a lapse of time sufficiently in excess of the incubation period for mosaic to insure recognition of the disease in plants inoculated prior to the first inspection. If no diseased plants are found during the second inspection, it can be assumed that secondary infection is not in operation and that the remaining plants will continue healthy. If diseased plants are found, however, it establishes the fact that secondary infections are going on. The field should be rogued as before, and a third inspection made after the same interval, i. e., 25 to 30 days. If the carriers remain active it may be necessary to repeat the process several times, and owing to the impossibility of recognizing the disease in inoculated plants before the end of the incubation period it is certain that plants which have become infected just before the inspection is made will escape detection. This emphasizes the necessity for making the first inspection early, preferably before leafhoppers or other sucking insects have appeared on the plants.

This procedure may result in perfect control or eradication of the disease or in partial control, the element of uncertainty being due to our inability to control the carriers. By it their activity can be rendered less effective by reducing the sources of inoculum to a minimum. It has effectually halted the progress of the disease into new territory in Porto Rico.

ELIMINATION BY GRINDING ALL CANE AND SECURING CLEAN SEED.

In badly infested sections the problem is manifestly complicated. Where 25 to 60 per cent or more of the plants in large fields are diseased, roguing is obviously out of the question. Such plantings should be allowed to mature. Every stalk of it should be ground, however, and the stubble plowed up and killed. This means, of course, that carefully selected seed must be imported for replanting. Fortunately there is still an abundance of healthy stock in Louisiana and other cane sections in the United States. As a result of its recent exhaustive survey for mosiac disease, the Office of Sugar-Plant Investigations of the Bureau of Plant Industry is in a position to furnish information on the nearest or most accessible source of clean seed for any region. Data have been secured on the prevalence of other diseases and insect pests in all cane regions, so that reasonable security against the dissemination of other cane maladies is assured.

EXCLUSION.

There are at the present time (October, 1919) a number of large cane areas in the United States not yet invaded by the mosaic disease. Cane planters in these areas should urge the enactment of

State legislation prohibiting the importing of cane into them from any source whatever until such time as it can be accompanied by an authentic certification of health. Such areas include the entire Bayou Teche district and the parishes to the north in Louisiana, consisting of St. Mary, Iberia, Vermilion, Lafayette, St. Martin, Acadia, St. Landry, Avoyelles, and Rapides. This is, of course, the most important disease-free area. (Fig. 2.) Other similar

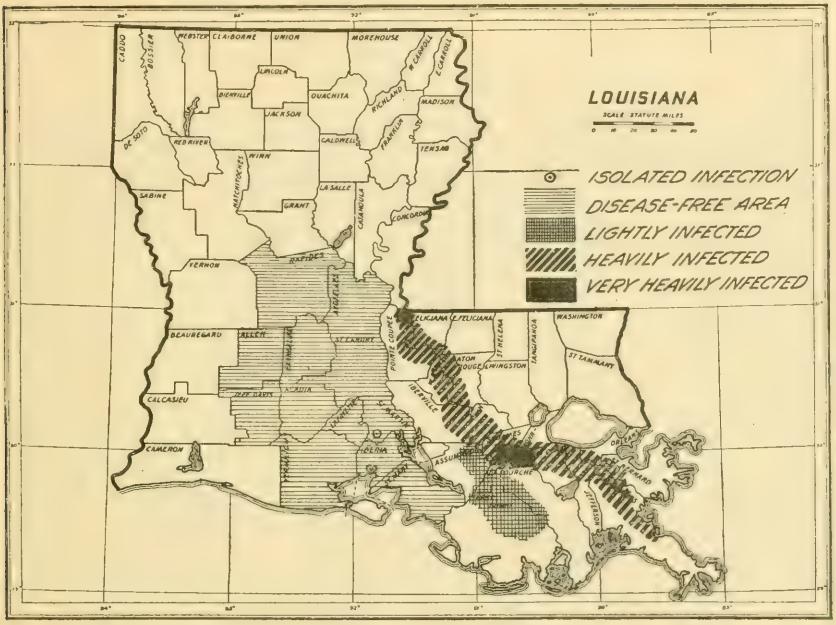


FIG. 3.—Map of Louisiana, showing the location of diseased areas of sugar cane in that State.

areas are the entire State of Mississippi with the exception of Biloxi; the entire State of Alabama except a small locality near Muscogee, Fla.; the entire State of Georgia except Grady County; and all parts of Florida other than those indicated in figure 4.

ERADICATION.[1]

Where the disease is present in small amount and in few well-defined areas, the possibility of quick and complete eradication exists. Such conditions are found in Mississippi, Alabama, and Florida. (See fig. 1.) The cane in these areas should all be ground during the present harvesting season and the stubble plowed up. As a precautionary measure, some crop other than a grass should be grown on the land for one year, after which cane may again be grown with safety. The two small infested areas in Alabama and

[1] In so far as it applies to the regions indicated, we concur in this suggestion by Mr. Wilmon Newell, Plant Commissioner of Florida.

Mississippi offer no difficulty at all. They can be destroyed with practically no loss to the owners, and the assurance of healthy crops in the future more than offsets the inconvenience of growing some other crop on the land now occupied by infected cane. The success of the measure in Florida is made possible by the present organization of the State plant board, which has already met the test of successfully handling more serious problems.

ELIMINATION BY PLANTING IMMUNE VARIETIES.

Success of the control measures suggested up to the present depends entirely upon the whole-hearted cooperation of all cane growers.

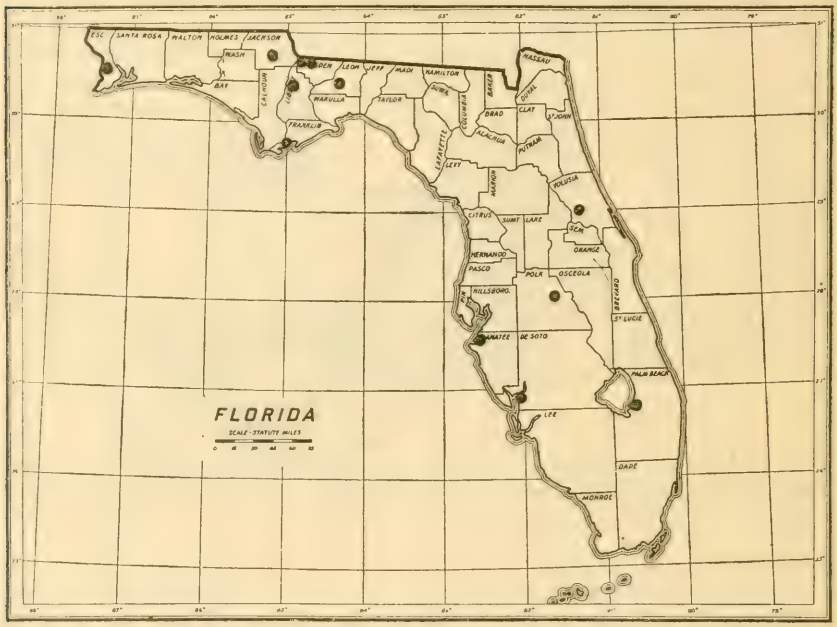


FIG. 4.—Map of Florida, showing the location of diseased areas of sugar cane in that State.

There yet remains a method, applicable only to certain regions, by which a planter can make himself wholly independent of any default on the part of his neighbors. A few varieties of sugar cane have been discovered that are absolutely immune to mosaic under all conditions. Most of them are of the type referred to as Japanese cane. Their origin is obscure. They have certain characteristics in common. All are tall growing with slender stalks. They stool abundantly, ratoon well, and produce an enormous tonnage. The sucrose content is not so high as in some of the broad-leaved canes, but in sugar per acre they take first rank with the best existing varieties. The Kavangire, Zwinga, Uba, Cayana 10, and numerous others imported by the office of Foreign Seed and Plant Introduction are

included among these varieties. The Cayana 10 has already won a well-deserved popularity among the farmers of the cane-sirup section in Georgia and northern Florida on account of its high tonnage and the excellent quality of sirup made from it. The Kavangire is used for manufacturing sugar in Argentina. Its estimable qualities are brought out in Table III.

FIG. 5.—Kavangire sugar cane (immune), at the left; G. C. 1070 (susceptible), at the center; Java 36 (susceptible but tolerant), at the right.

TABLE III.— *Yield and analysis of Kavangire sugar cane compared with other standard varieties.*[1]

Variety.	Average weight of single canes.	Weight of cane per hectare.[3]	Brix scale.	Sucrose.	Purity.	Weight of sugar per hectare.[3]
	Kilos.[2]	*Kilos.*[2]	*Degrees.*	*Per cent.*	*Per cent.*	*Kilos.*[2]
Kavangire	0.68	166,850	17.84	15.68	87.5	16,090
Java 36	1.36	117,300	17.55	15.34	87.4	11,024
Java 213	.84	95,725	17.54	15.79	89.96	9,533
Louisiana 60	1.87	118,125	17.32	15.34	87.05	10,973
Java 139	1.10	89,975	16.67	14.41	86.40	7,853
Rayada (Louisiana Striped)	1.71	94,150	18.26	16.39	89.74	9,714
Java 234	.95	75,550	19.02	16.66	87.08	7,703
Morada (Louisiana Purple (?))	1.28	72,925	16.69	14.54	87.07	6,354
Honduras	1.23	76,575	16.98	14.36	83.88	5,998
Java 100	1.00	79,675	16.03	13.57	89.68	6,456
Tamarin	.95	33,325	19.15	17.50	91.54	3,940

[1] Bennett, A. G. Informe de subestaciones para el año 1914. *In* Rev. Indus. y Agr. Tucuman, año 5, p. 208–209. 1914.

[2] A kilo is the equivalent of 2.2 pounds.

[3] A hectare is the equivalent of 2.47 acres.

Figure 5 shows a row of Kavangire cane on the left; a susceptible variety, G. C. 1070, at the center; and a diseased but tolerant variety, Java 56, on the right. Unfortunately, the Kavangire variety is a long-season cane and therefore not suitable for conditions in Louisiana. The possibility of breeding more early maturing varieties from these parents is being investigated.

Several of the broad-leaved varieties of cane originated at the Sugar Cane Experiment Station at Audubon Park, La., appear to be immune. Although equally exposed to the contagion, no individuals of these varieties have become affected, while practically every plant of the scores of other varieties surrounding them is diseased. They have been under observation for too short a time, however, to demonstrate that their apparent immunity is permanent.

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